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ROYAL AIRCRAFT ESTABLISHMENT

Farnborough. Hants.

FINAL NOTE ON THE RELATIVE SUITABILITIES OF D.T.D. 303 AND D.T.D. 327 RIVETS FOR D.T.D. 118 MAGNESIUM ALLOY SHEET

by

S. ACKROYD, B.Sc.

and

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Class number 621.884.002.3 : 669.715(42) : 669.721.5(42) D.T.D.118

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August, 1946

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Final Note on the Relative Suitabilities of D.T.D.303 and D.T.D.327 Rivets for D.T.D.118 Magnesium Alloy Sheet

by

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and
H.C. Cooks, Ph.D., F.R.I.C.

R.A.E. Ref: Mat M5/8740A/SA/171
M o S Ref: Res.Mat.1266/R.D.Mat (M)1

SUMMARY

The rate of contact corrosion between D.T.D.118 magnesium alloy sheet and D.T.D.327 aluminium alloy rivets was found to be greater than that between D.T.D.118 sheet and D.T.D.303 aluminium alloy rivets when subjected to a sea-water spray test. This was so with both stressed and unstressed specimens; both in conjunction with various protective painting schemes, and without protective paint.

Visual examination was confirmed by strength tests on the corroded specimens and by measurement of the depth of corrosion on the magnesium alloy sheet.

The greater rate of corrosion with the D.T.D.327 rivets is considered to be due to factors such as:-

(a) lower hydrogen overvoltage with D.T.D.327 rivets than with D.T.D. 303 rivets

(b) a greater difference of potential between D.T.D.327 and D.T.D.118 than between D.T.D.303 and D.T.D.118.

It is concluded that D.T.D.327 rivets are unsuitable for replacing D.T.D.303 rivets where they are used for joining D.T.D.118 sheet.

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1 Introduction

After exposure to high tropical temperatures, rivets to specification D.T.D.303, which are made from an aluminium alloy containing 5% magnesium, are liable to fail by stress corrosion cracking. It was suggested that these rivets which have been used for joining magnesium alloy sheet to specification D.T.D.118, as well as for joining aluminium alloys, should be replaced by rivets made in a low copper duralumin type alloy to D.T.D.327. It was suspected, however, that the contact corrosion between D.T.D.327 and D.T.D.118 would be greater than that between D.T.D.303 and D.T.D.118, and tests were made to obtain evidence as to whether this suspicion was justified.

2 Preparation and Corrosion of Specimens

Each of 120 of the 132 specimens used in the investigation consisted of a pair of $3\frac{3}{4}$" x 1" x 16 S.W.G. D.T.D.118 magnesium alloy strips riveted end to end with either a D.T.D.303 or D.T.D.327 rivet, and having a $\frac{3}{4}$" overlap. In all cases the magnesium alloy sheet was chromate treated to Specification D.T.D.911 in Bath (iii) (hot half hour bath), and one of the following materials was used as a jointing compound.

(1) D.T.D.279B temporary metal protective. (Lanolin pigmented with zinc chrome.)

(2) D.T.D.369A "Duralac" jointing compound. (Long oil base pigmented with barium chromate.)

(3) "Solac" UP4. (Synthetic undercoat paint, pigmented with zinc chrome to D.T.D.377.)

Sixty of the specimens were given two coats of organic protective and sixty left unpainted. (See Table I.) Sixty of the specimens were stressed continuously during the corrosion tests, and sixty were exposed without being stressed.

Five specimens with each type of rivet were tested in all possible combinations of the conditions mentioned (see Table I).

The corrosion test consisted of spraying the specimens three times daily with seawater from the English channel. The ambient temperature during the test varied between 65°F and 75°F. The method adopted for stressing sixty specimens for a period of eight weeks was to join them by links and pins made from magnesium alloy in six series of ten specimens. One end of each series was fixed, and to the other end, load was applied by means of a weighted lever. The load applied was two thirds of the 0.1% proof stress of the joint, this being 300 lb. for each type of rivet.

Twelve larger test pieces, for observation, each consisting of a pair of chromate treated D.T.D.118 sheets 9" x $3\frac{3}{4}$" x 16 S.W.G. riveted by a single row of rivets at 1" pitch along the longer edge were also prepared and exposed to the seawater spray in certain combinations of the conditions mentioned. (See Table I.)

3 Tests and Observations

3.1 Visual Examination

From the beginning of the test it became increasingly apparent that with every painting scheme and with the unpainted specimens, the amount of corrosion products, both on the rivet head and on the sheet near the rivet, was considerably greater with the D.T.D.327 rivets than with the D.T.D.303 rivets. This feature can be seen in the photographs (Figs. 1-4).

Fig.1 shows a representative from each group of five single riveted unstressed specimens after 25 days corrosion.

Fig.2 shows the (visually) most corroded and least corroded of each group of five single riveted unstressed specimens after eight weeks corrosion.

Fig.3 shows the same as Fig.2, but for the stressed specimens. (The markings at each end of these specimens are due to paint from the magnesium alloy links, and not to corrosion.)

Fig.4 shows four of the large painted specimens after eight weeks corrosion.

3.2 Strength tests

After eight weeks corrosion all the single riveted joints were tested to destruction in tension (i.e. with the rivet in shear) and the results tabulated in Table II. Three failures were due to the rivet shearing, 2 to the sheet breaking at the pins and 115 to the sheet failing near the rivet.

An analysis of variance was made to determine if observed strength differences between single factors were significant. As was suspected, the D.T.D.303 riveted joints were found to be stronger than the D.T.D.327 riveted joints, the difference in strength being highly significant. It was also found that the difference in strength between painted and unpainted specimens was highly significant, the painted ones being the stronger and that the stressed specimens were significantly stronger than the unstressed ones. There was no significant difference in the strength of specimens treated with different jointing compounds. That the stressed specimens should be significantly stronger than the unstressed ones seems to indicate that the stressing caused work hardening of the magnesium alloy sheet.

3.3 Measurement of Corrosion

To verify the strength results, the maximum depth of corrosion on the magnesium alloy sheet was measured on the following specimens:-

Specimens Examined	Rivet	Stress	Paint
CD 22, 23, 24	D.T.D.303	Unstressed	Unpainted
GH 22, 23, 24	D.T.D.327		
CD 32, 34 EF21	D.T.D.303	Stressed	
GH 33, 34 EF27	D.T.D.327		
CD 8, 9, 10	D.T.D.303	Unstressed	Painted
GH 6, 8, 9	D.T.D.327		
AB 17, 18, 20	D.T.D.303	Stressed	
EF 17, 18, 20	D.T.D.327		

The fractured specimens were cut longitudinally down the middle of the strip, the rivet removed and the cut face of each strip polished and projected on to the screen of a Vickers Projection Microscope. The maximum depth of corrosion of each strip was measured. This depth was found to be statistically significantly greater for the D.T.D.327 than for the D.T.D.303 riveted specimens, the average depths being 29% and 12% of the uncorroded thickness respectively.

3.4 Microscopical Examination of Rivets

The rivet from each of the following specimens was examined microscopically to identify the type of corrosion.

Micro-Specimens	Rivet	Stress	Paint
CD 22, 23, 24, 5	D.T.D.303	Unstressed	Unpainted
GH 22, 23, 24	D.T.D.327	Unstressed	Unpainted
CD 32, 24 EF21	D.T.D.303	Stressed	Unpainted
GH 33, 34 EF27	D.T.D.327	Stressed	Unpainted
EF 29	D.T.D.327	Stressed	Painted

All the rivets showed some signs of pitting corrosion, the D.T.D.327 rivets slightly more so than the D.T.D.303 rivets, but in neither type was there any susceptibility to intercrystalline corrosion, although there was some corrosion penetration at isolated places where the rivet head had been cold worked at formed and preformed heads. At many of the corners between head and shank large cracks were found, but these were attributed to either the riveting or strength testing. CD5 and CD22 were two of the three rivets which sheared during the strength tests and EF29 was the specimen which had the lowest strength. None of these three showed corrosion characteristics different from the other rivets. (The low strength value of EF29 and possibly one or two others was attributed to a possible crack in the sheet due to the specimen being bent during riveting.)

3.5 Determination of Corrosion Current, Electrode Potential and Overvoltage

A circuit was arranged whereby the current flowing between a D.T.D.118 sheet and a rivet, placed in seawater, could be measured. For this test all protective coatings were removed from the rivet and sheet, which were then placed about 1½ inches apart in seawater. The current flowing was measured over a period of hours by means of a recording milliammeter placed in the external circuit, the latter being of low resistance (0.055 ohms). The large difference of current obtained using the two kinds of rivets (see Table III) caused determinations of electrode potential and overvoltage of the rivets to be made.

The electrode potential in seawater of each type of rivet and of the sheet was measured by means of a valve potentiometer, the potentials being measured against a saturated calomel electrode with free access of air at 20°C. The difference of potential of the D.T.D.327-D.T.D.118 pair was found to be slightly larger than that of the D.T.D.303-D.T.D.118 pair (see Table III) but this only partly explains the large difference of corrosion current.

Hydrogen overvoltage is a factor which opposes the flow of corrosion current. Hence, if the overvoltage with the D.T.D.327 rivets was not as high as that with the D.T.D. 303 rivets, this would also be a factor in explaining the much higher corrosion current with the D.T.D.327 rivets.

The measurements of hydrogen overvoltage were carried out (at intervals during 24 hours) by the "direct" method, i.e. with the polarising current flowing continuously and maintained at a constant value. Actual rivets and magnesium alloy sheet with protective coatings removed were used as electrodes. The seawater in which the metals were immersed had been previously saturated with magnesium hydroxide by electrolysis using a platinum cathode and magnesium anode. The pH of the seawater was measured by means of the glass electrode before and after overvoltage measurements. The overvoltages were obtained by subtracting the potentials of the reversible hydrogen electrode in the same solution from the measured cathodic potentials, while the hydrogen electrode potentials were obtained from the observed pH values (see Table III).

As was suspected the overvoltage with the D.T.D.327 rivets was found to be lower than with the D.T.D.303 rivets. It was also observed that with the D.T.D.303 rivet the overvoltage rises with time while with the D.T.D.327 rivet it falls with time. In addition, the overvoltage at the higher current density with the D.T.D. 327 rivets is, after 24 hours, not only lower than with the D.T.D.303 rivet, but also lower than with the D.T.D.327 rivet at the lower current density. This suggests that the effect of overvoltage is cumulative.

4 Conclusions

The rate of corrosion in seawater between D.T.D.118 sheet and D.T.D.327 rivets was found to be greater than that between D.T.D.118 sheet and D.T.D.303 rivets, the corrosion current with the D.T.D.327 rivet being about 30 times that with the D.T.D.303 rivet when in contact with the same magnesium alloy sheet.

Experimental evidence has been obtained showing that this is due to:-

(a) Lower hydrogen overvoltage with the D.T.D.327 rivets than with the D.T.D.303 rivets.

(b) Greater difference of potential between D.T.D.327 rivets and D.T.D.118 sheet than between D.T.D.303 rivets and D.T.D.118 sheet.

Factor (a) appears to be more important than factor (b).

Microscopical examination revealed no tendency to intercrystalline corrosion in either rivet, although had the D.T.D.303 rivets been previously subjected to tropical temperatures this type of corrosion might have occurred.

It is concluded that D.T.D.327 rivets are unsuitable for replacing D.T.D.303 rivets where they are used for joining D.T.D.118 sheet.

REFERENCE

Ref.No.	Author	Title, etc.
1	Metcalfe, G.J.	The effect of tropical temperature on the microstructure and corrosion resistance of 5% magnesium aluminium alloy rivets to Specification D.T.D.303. R.A.E. Report No. M.7925A, June, 1945.

Attached:
Tables I - III
Figs.1 - 4 = Negs. M.8740A.

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TABLE I

Details of Protective Schemes, and Designation of Specimens

				Unpainted			Painted		
Jointing Compound Primer Finishing Coat				D.T.D.279B – –	D.T.D.369A – –	UP4 – –	D.T.D.279B D.T.D.279B D.T.D.279B	D.T.D.369A UP4 Nitrocellulose White	UP4 UP4
Specimen Number	Unstressed Specimens	*Size B	D.T.D.303 Rivets	J1	LJ3	–	KL1 MN1	KL3 MN3	– –
			D.T.D.327 Rivets	J2	LJ4	–	KL2 MN2	KL4 MN4	– –
		*Size A	D.T.D.303 Rivets	AB 26 AB 27 AB 28 AB 29 AB 30	CD 1 CD 2 CD 3 CD 4 CD 5	CD 21 CD 22 CD 23 CD 24 CD 25	AB 22 AB 23 AB 24 AB 9 AB 10	CD 6 CD 7 CD 8 CD 9 CD 10	CD 26 CD 27 CD 28 CD 29 CD 30
			D.T.D.327 Rivets	EF 1 EF 2 EF 3 EF 4 EF 5	GH 1 GH 2 GH 3 GH 4 GH 5	GH 21 GH 22 GH 23 GH 24 GH 25	EF 6 EF 7 EF 8 EF 9 EF 10	GH 6 GH 7 GH 8 GH 9 GH 10	GH 26 GH 28 GH 29 GH 30 GH 31
	Stressed Specimens	*Size A	D.T.D.303 Rivets	AB 11 AB 12 AB 13 AB 14 AB 31	CD 11 CD 12 CD 13 CD 14 CD 15	CD 31 CD 32 CD 33 CD 34 EF 21	AB 16 AB 17 AB 18 AB 19 AB 20	CD 16 CD 17 CD 18 CD 19 CD 20	EF 22 EF 23 EF 24 EF 25 EF 26
			D.T.D.327 Rivets	EF 11 EF 12 EF 13 EF 14 EF 15	GH 11 GH 12 GH 13 GH 14 GH 15	GH 32 GH 33 GH 34 EF 27 EF 28	EF 16 EF 17 EF 18 EF 19 EF 20	GH 16 GH 17 GH 18 GH 19 GH 20	EF 29 EF 30 EF 31 EF 32 EF 33

*Size A – small specimens with single riveted joints
Size B – large specimens with row of 9 rivets

TABLE II

Results of Strength Tests on Corroded Specimens

Jointing Compound			Unpainted						Painted					
			D.T.D.279B		D.T.D.369A		UP4		D.T.D.279B		D.T.D.369A		UP4	
			No.	Load (lb)	No.	Load (lb)	No.	Load (lb)	No.	Load (lb)	No.	Load (lb)	No.	Load (lb)
Designation of Specimen and Failing Load	Unstressed Specimens	D.T.D.303 Rivets	AB 26	758	CD 1	720	CD 21	745	AB 22	738	CD 6	660	CD 26	765
			27	761	2	621	22*	623	23	702	7	740	27	774
			28	775	3	771	23	720	24	683	8	701	28	784
			29	752	4	661	24	704	9	550	9	696	29	815
			30	680	5*	715	25	760	10	722	10	707	30	766
			Mean	745		698		710		679		701		781
		D.T.D.327 Rivets	EF 1	645	GH 1	663	GH 21	545	EF 6	650	GH 6	698	GH 26	655
			2	670	2	548	22	560	7	758	7	692	28	375
			3	696	3	495	23	535	8	695	8	658	29	760
			4	643	4	518	24	468	9**	805	9	697	30	693
			5	655	5	628	25	670	10	656	10	725	31	693
			Mean	662		570		556		713		694		635
	Stressed Specimens	D.T.D.303 Rivets	AB 11	750	CD 11*	772	CD 31	638	AB 16	805	CD 16	687	EF 22	810
			12	722	12	661	32	793	17	790	17	745	23	705
			13	735	13	816	33	698	18	785	18	795	24	750
			14	658	14	739	34	803	19	825	19	802	25**	821
			31	738	15	710			20	650	20	792	26	713
							EF 21	763						
			Mean	721		740		739		771		764		760
		D.T.D.327 Rivets	EF 11	664	GH 11	558	GH 32	612	EF 16	755	GH 16	680	EF 29	352
			12	683	12	617	33	571	17	694	17	776	30	757
			13	648	13	701	34	639	18	737	18	765	31	670
			14	534	14	715	EF 27	642	19	775	19	852	32	780
			15	565	15	672	28	732	20	769	20	730	33	731
			Mean	619		653		639		746		761		658

*Specimen failed due to rivet shearing

**Specimen failed due to sheet failing at the pins.

In all other specimens failure was due to the sheet failing near the rivet.

TABLE III
Current and Potential Measurements on Magnesium Alloy Sheet
in contact with Aluminium Alloy Rivets

(a) Measurement of Corrosion Current

The current flowing between a D.T.D.327 rivet and D.T.D.118 sheet when placed about $1\frac{1}{4}$" apart in seawater and connected externally was about 30 times as great as the current flowing between a D.T.D.303 rivet and a D.T.D.118 sheet under similar conditions.

(b) Measurement of Potential Differences

The potentials, measured in seawater with free access of air at 20°C., against a saturated calomel electrode were:-

	D.T.D.303 rivet	D.T.D.327 rivet	D.T.D.118 sheet
Potential	-0.77 volt	-0.64 volt	-1.65 volt

Hence P.D. between D.T.D.303 rivet and D.T.D.118 sheet = 0.88 volts
P.D. between D.T.D.327 rivet and D.T.D.118 sheet = 1.01 volts.

(c) Measurement of Overvoltages

Rivet	D.T.D.303		D.T.D.327		
Experiment	a	b	c	d	e
Current Density at Rivet (Milliamps/sq.cm)	1	1	1	1	10
pH at beginning of experiment	9.70	9.70	9.70	9.80	9.70
pH at end of experiment	9.52	9.54	9.52	9.53	9.52
Overvoltage at beginning of experiment (volts)	0.82	0.835	0.80	0.80	0.93
Overvoltage at end of experiment (volts)	0.92	0.925	0.63	0.635	0.54

FIG. 1

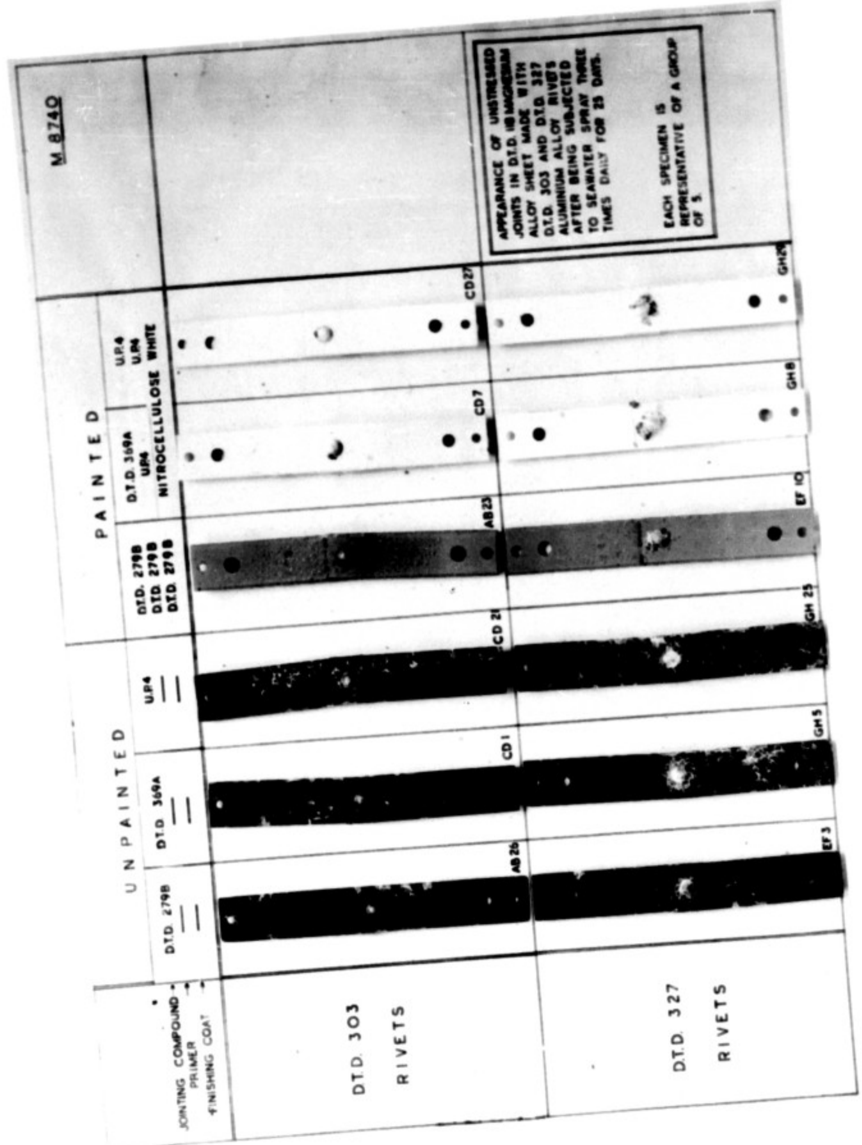

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FIG.2

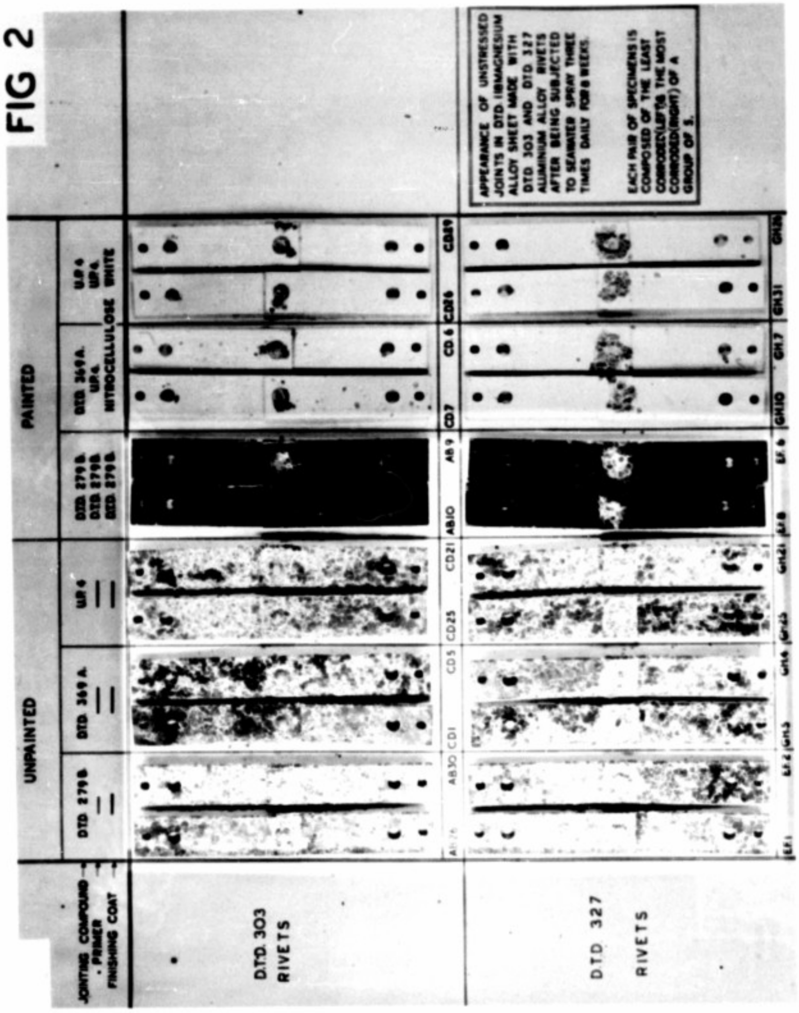

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FIG. 3

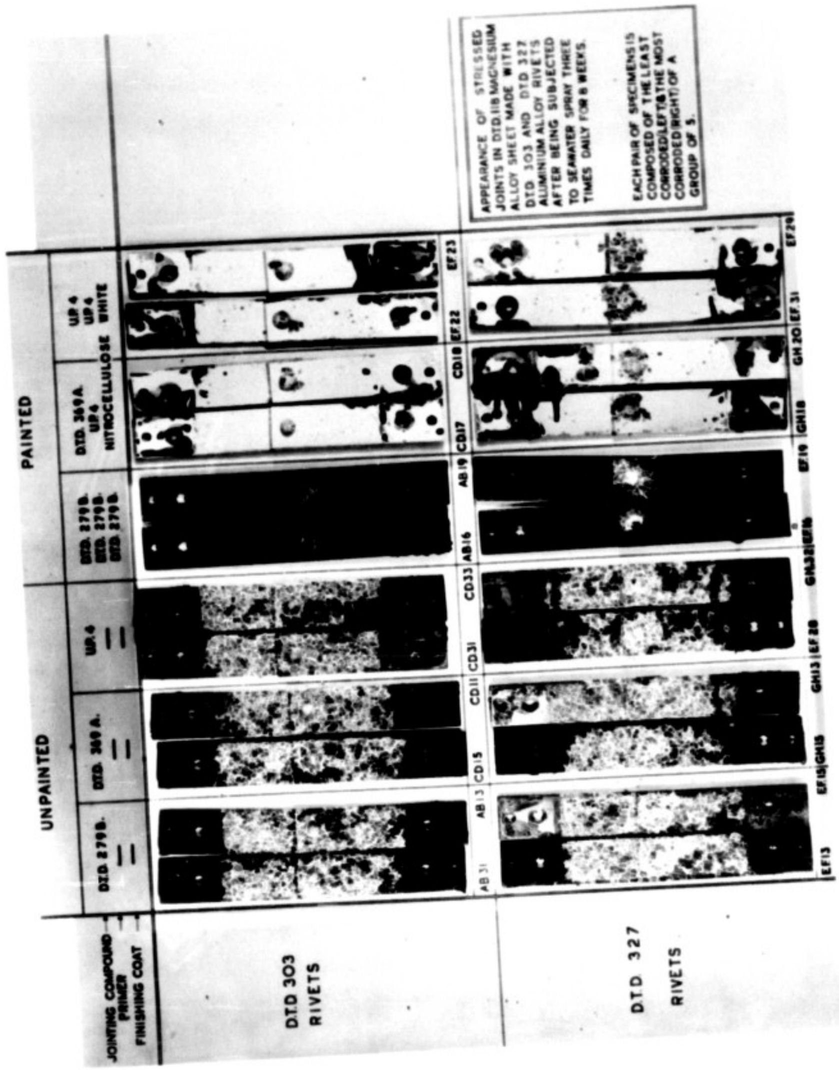

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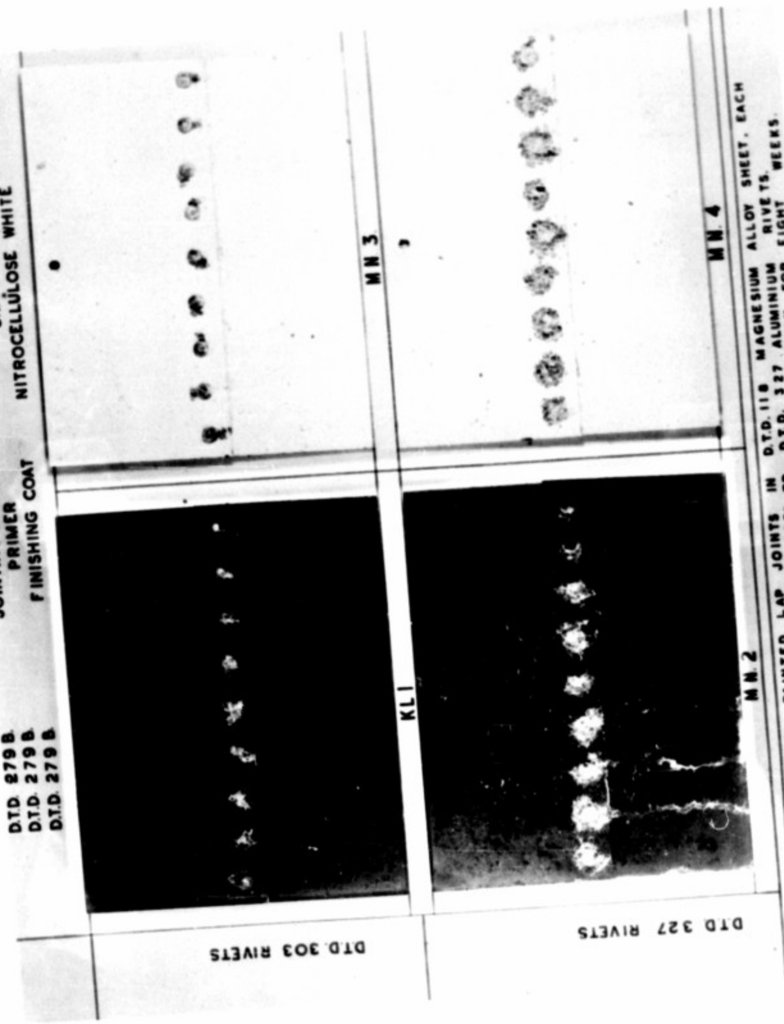
FIG. 4



APPEARANCE OF UNSTRESSED, PAINTED LAP JOINTS IN D.T.D. 118 MAGNESIUM ALLOY SHEET, EACH MADE WITH A SINGLE ROW OF NINE D.T.D. 303 OR D.T.D. 327 ALUMINIUM RIVETS. THE JOINTS WERE SUBJECTED TO SEA WATER SPRAY THREE TIMES DAILY FOR EIGHT WEEKS.

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